

ADVANCES IN BNL'S POLARIZED ION SOURCE DEVELOPMENT\*

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Introduction

Polarized protons have been accelerated in the AGS to 22 GeV. The polarized source presently used produces 30-40  $\mu\text{A}$  of  $\text{H}^+$  at 75-80% polarization, in 500  $\mu\text{s}$  pulses, 0.5 Hz. This is three orders of magnitude lower in intensity than normal  $\text{H}^+$  operation, and higher intensities are desired. There is a program in the AGS department to develop a higher intensity source, and the proposed source is shown schematically in Figure 1. This is a ground state atomic beam source with an atomic beam cooled to 6 K, spin selection and focusing via a superconducting solenoid (shown) or a sextupole system, and an ionizer for  $\text{H}^+$  production based on the charge exchange of  $\text{H}^0$  with  $\text{D}^+$ . Work is in progress on all three components, and will be described in the following sections.

Cold Atomic Beam Source

The idea of improving the performance of a polarized atomic hydrogen beam by cooling of the initial  $\text{H}^0$  atoms is not a new one [1]. Roughly, one expects a gain in the fraction of atoms that can be focused by the spin selection/focusing system (i.e. flux into the ionizer) to be proportional to  $1/T$ . Due to the lower velocity of the atoms, the density in the ionization region should therefore be increased by the factor of  $(1/T)^{3/2}$ . This gain, however, will be diminished if  $\text{H}^0$  flux is lost via recombination or choking of the flow during cooling, or if the ionizer cannot be properly matched to this larger emittance  $\text{H}^0$  beam [2]. To date, while cooling of atomic beams has improved the output from polarized sources, the gains have not been as dramatic as  $(1/T)^{3/2}$ .

Figure 2 shows the apparatus used for the first cold atomic beam experiments. Atomic hydrogen is produced in a conventional room temperature rf dissociator. The  $\text{H}^0$  atoms then flow through either a teflon or glass transition section, in contact with a liquid nitrogen cooled surface, which is typically held at  $\sim 130$  K, and into a copper accommodator channel which could be cooled to temperatures as low 4.2 K by contact with the cold foot of a liquid helium cryostat (or as low as 3.2 K by pumping on the liquid helium). The atoms are cooled via thermal heat transfer to the walls of the channel, and therefore materials and temperatures must be

chosen so that  $\text{H}^0$  recombination on these walls is minimized. The teflon or glass transition section at 130 K, and frozen molecular hydrogen on the 6 K copper accommodator, provide low recombination rate surfaces. At some range between approximately 80 K and 20 K, however, one would very likely encounter a bad temperature/surface combination and lose flux, so in our design this temperature range is jumped via a 0.3 mm gap between the 130 K teflon and 6 K copper sections. The skimmer following the accommodator was graphite coated, and cooled to under 4K by pumping on helium. This provided very effective cryopumping of  $\text{H}_2$ , thereby reducing beam losses from  $\text{H}_2$  scattering.

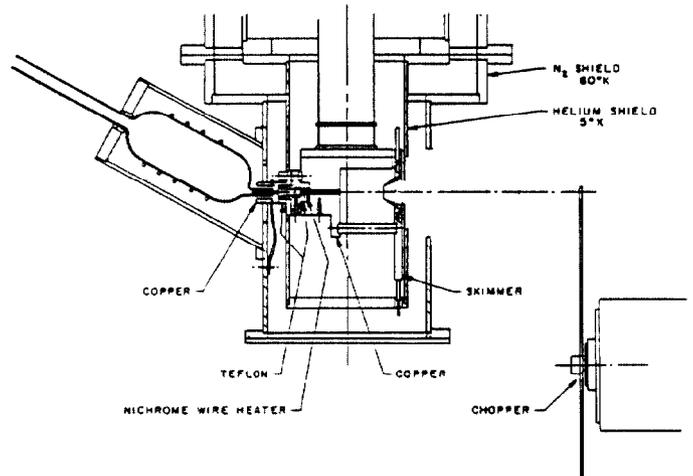


Fig. 2 Schematic of the interior of the cold hydrogen beam test box.

The  $\text{H}^0$  beam density was measured with a quadrupole mass spectrometer located 70 cm from the accommodator, and a beam chopper could be inserted 15 cm from the accommodator for a time-of-flight measurement of the beam velocity distribution. Figure 3 shows the measured  $\text{H}^0$  density as a function of the accommodator temperature, for a 3 mm diameter accommodator, and the measured

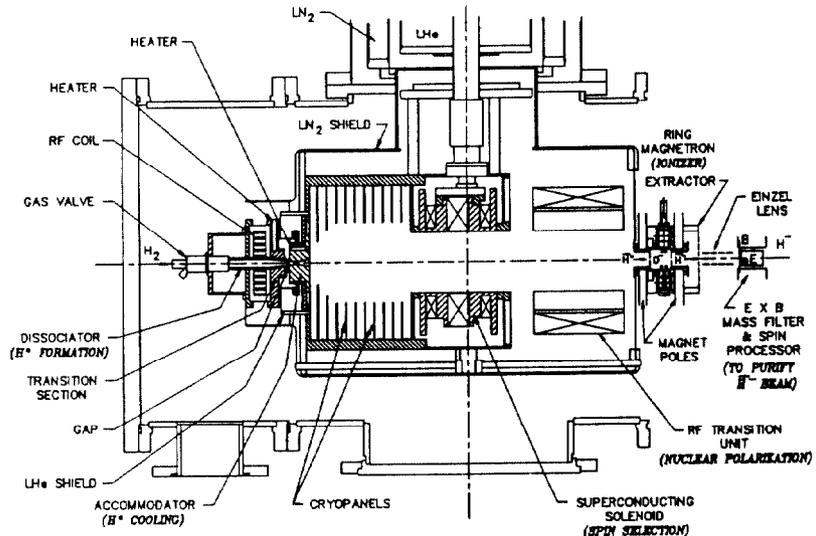


Fig. 1 Schematic of the high intensity polarized  $\text{H}^+$  source presently under development.

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velocity distributions for the two peaks are shown in Figure 4. The narrow velocity distribution of the 5.8 K peak should be very beneficial for the atomic beam optics. The measured forward fluxes were  $9.4 \times 10^{18}$  and  $4 \times 10^{19}$  atoms/s/sterradian at 5.8 K and 26 K, respectively. More details of this experimental setup and a discussion of the results can be found in [3].

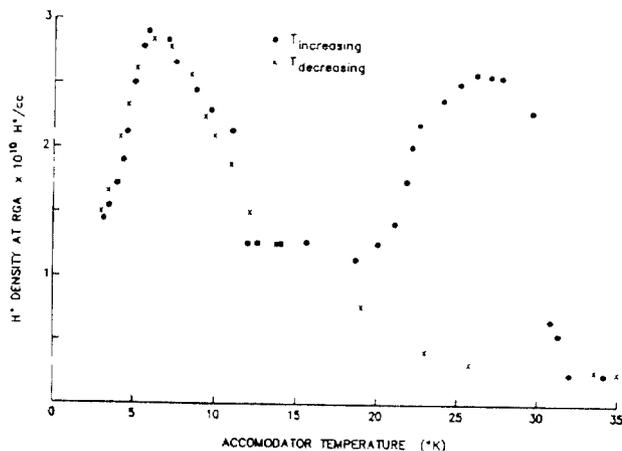


Fig. 3 Variation of hydrogen beam density with accomodator temperature.

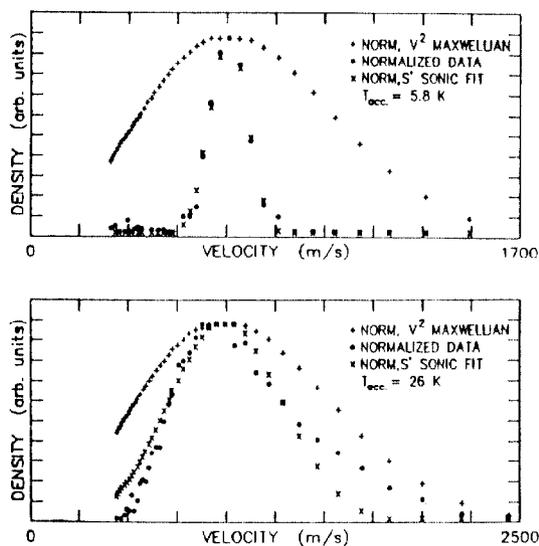


Fig. 4 Results of velocity distribution measurement with  $T_{acc} \sim$  (a) 6 K and (b) 26 K.

Several modifications were then made to the atomic beam stage, in parallel with preparations for tests of the focusing of  $H^0$  using a superconducting solenoid (to be discussed in the next section). The new atomic beam geometry is as shown in Figure 1. The volume of the pyrex dissociator was reduced from that of the initial experiments. The teflon transition section was eliminated, with the exit of the pyrex dissociator cooled instead (the 0.3 mm gap was maintained between the dissociator exit and the copper accomodator). The cryopump/skimmer was replaced with more open cryopanel. Finally, the accomodator channel geometry was changed to one having a 15mm long by 3mm diameter straight section, followed by a section 15mm long, which tapered out to 10mm diameter at the exit. This shape was motivated by the thought that if the nozzle area were increased as the velocity of the atoms was decreasing through the channel, the  $H^0$  density could be kept below that at which 3-body recombination becomes important (estimated to be on the order of  $10^{17} H^0/cm^3$ ). After making these modifications, the  $H^0$  density was again measured with the quadrupole mass spectrometer, which was now located 91 cm from the

accomodator. Densities as high as  $6 \times 10^{11}/cm^3$  were measured at 6 K. If one makes a  $1/r^2$  correction for the increased distance to the detector in this case, the density is approximately a factor of 30 higher than that obtained with the initial atomic beam geometry shown in Figure 2. The temperature dependence seen in Figure 3 was again observed qualitatively. The velocity distribution could not be measured with the new setup.

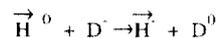
### Spin Selection and Focusing

The force on the  $H^0$  atoms for spin selection and focusing comes from the interaction of the electron magnetic moment with a magnetic field gradient. This field gradient is usually provided by sextupole magnets, which have good optical properties since the gradient varies linearly with radius in the aperture. The use of a type of superconducting solenoid for focusing was proposed by Niinikoski, and is described in [4]. By taking advantage of the higher fields obtainable in such a coil, one could hopefully build a magnet having a suitable field gradient over a larger aperture than is possible in a conventional sextupole system. In a collaboration with T. Niinikoski (CERN), it was decided to test such a solenoid. The solenoid consists of three coils connected in series, with the current in the outer two counter to the current in the middle coil. This gives a high field at the inner diameter of the coils and a weak field on axis, i.e. a large magnetic field gradient, required for focusing. The three coil system was built having an i.d. of 9.4 cm and an overall length of 10 cm. A field of 5.2 T was obtained at the coil i.d., at a current of 107 A. Field maps generated with the POISSON program for our geometry showed a disadvantage of the solenoid for this type focusing, in that the gradient is very nonlinear. Because of this, track-tracing calculations of the  $H^0$  beam through the solenoid showed large aberrations in the focusing. Therefore, although the ray tracing calculations predicted a significant focusing from the solenoid, it did not appear to be as favorable as a sextupole. First tests of the solenoid with the  $H^0$  beam, as shown in Figure 1, actually showed a slight decrease in the  $H^0$  density, measured 65 cm away from the coil exit, when the solenoid was energized. To test our suspicion that gas scattering may be the problem, the accomodator diameter was then reduced to 3mm, in order to decrease the  $H^0$  density. In this case, focusing was observed, as is shown in Figure 5. The fact that the solenoid field is not high enough to allow one to pass through the maximum density is in disagreement with our calculations. As Figure 6 shows, a decrease in the focusing factor was observed as the unfocused atomic beam density was increased, seeming to confirm our suspicion that beam scattering ( $H^0$  on  $H^0$ ) is reducing the focusing effect at higher densities. At the much higher densities obtained with the flared accomodator, we suspect that atoms from the defocused component of the  $H^0$  beam are scattered off the cold solenoid wall, further raising the  $H^0$  density in the solenoid and causing the observed drop in the  $H^0$  density measured downstream when the solenoid is energized.

While further experiments and analysis of these solenoid results are planned, the alternative of focusing with a sextupole is being pursued. Track-tracing calculations have shown that one can form a much better focused beam with the sextupole, particularly with the narrow velocity distribution of the 6 K atomic beam. The track-tracing calculations, however, neglect gas scattering effects, which now appear to be quite important. The sextupole design will be as open as possible so that the defocused atoms will not interfere with the primary beam.

### Ring Magnetron Ionizer

The use of the reaction:



for polarized  $H^+$  production was proposed by Haerberli [5] as being favorable due to its large cross section. The ring magnetron ionizer was proposed as a way to take advantage of the above reaction, while overcoming problems with space charge blowup of the ion-

ized beam [6]. The ionizer is shown schematically in Figure 7. Its operation is basically the same as a normal magnetron surface-plasma source, although with an inverted geometry, i.e. the cathode is the outer and the anode the inner of two concentric cylinders.  $D^-$  ions are produced on the Cs-coated molybdenum cathode, and are accelerated away from the cathode, through slits in the anode, and into the central region of the ionizer. Enough  $D^+$  ions from the source plasma diffuse into the central region to provide space charge neutralization of the  $D^-$  and  $H^-$ . Polarized  $H^0$  passes axially through the central region and is ionized. The short length of this ionizer, compared to other techniques, gives it the advantage of having a large acceptance for the polarized atomic beam.

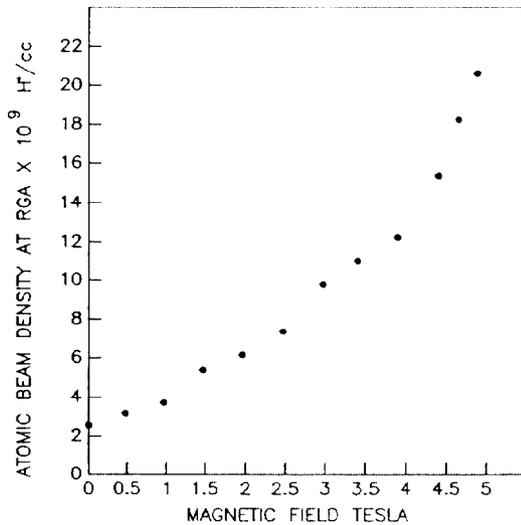


Fig. 5 Variation of  $H^0$  density with superconducting solenoid magnetic field.

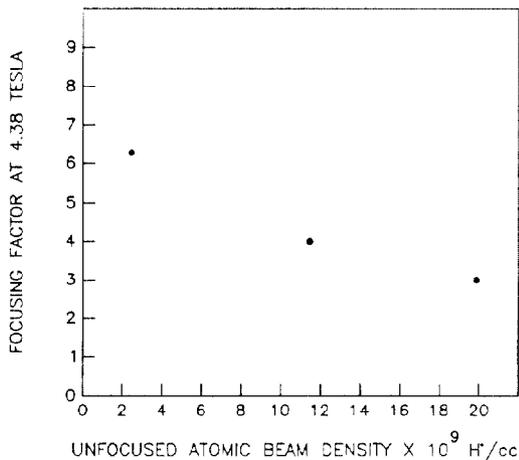


Fig. 6 Variation of the focusing factor (ratio of density at  $B=4.38$  T to density at  $B=0$ ) vs. density at  $B=0$ .

To test the ionization, so far only unpolarized  $H^0$  has been passed through the magnetron. With an estimated  $H^0$  density of  $10^{12}$  atoms/cm<sup>3</sup> in the center of the ionizer, 500  $\mu$ A of  $H^-$  coming from the resonant charge exchange was extracted at 2-3 kV. The ionizer has subsequently been inserted in place of an electron bombardment ionizer on an old polarized source, and a complete extraction and beam transport system added. Unfortunately, the present geometry is less favorable with respect to pumping around the ionizer, and we have not yet seen performance as good as on the test stand. Up to 50  $\mu$ A of  $H^-$  has been extracted with an estimated

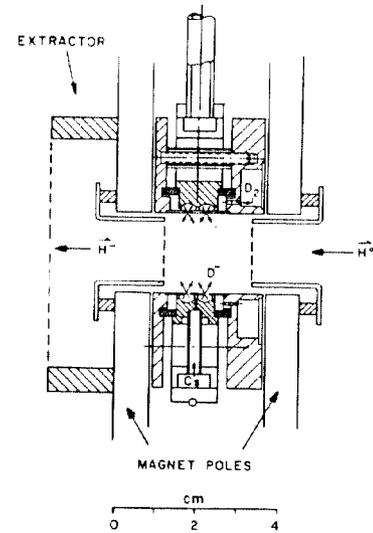


Fig. 7 Schematic of the ring magnetron  $D^-$  charge exchange ionizer.

$H^0$  density in the ionizer of  $6 \times 10^{11}$  atoms/cm<sup>3</sup> (again with unpolarized  $H^0$  injected). This flux is calculated from a measurement of the  $H^0$  density taken downstream of the ionizer with a quadrupole mass spectrometer. The measurement is taken with the ionizer off, and the density is then calculated in the center of the ionizer assuming a  $1/r^2$  falloff of density with distance from the dissociator (there are no sextupoles in the present configuration). We feel that the poorer performance is most likely due to loss of  $H^0$  flux before entering the ionizer from gas scattering on  $D_2$  from the magnetron. We are presently testing several ideas to improve the pressure in the magnetron region.

#### Summary

The performance of the 6 K  $H^0$  beam source has exceeded expectations. Since gas scattering seems to be a problem in the superconducting solenoid, we will be testing a permanent magnet sextupole for spin selection. The resulting polarized atomic beam will then be combined with an rf transition unit and the ring magnetron ionizer, with a final polarized  $H^-$  current on the order of a milliamper as our goal.

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